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**Citation for published version:**

Harrison, GP & Whittington, HW 2002, Analysing climate change risk in hydropower development. in *Proceedings of HydroVision 2002*.

**Link:**

[Link to publication record in Edinburgh Research Explorer](#)

**Document Version:**

Peer reviewed version

**Published In:**

Proceedings of HydroVision 2002

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# **Analysing Climate Change Risk in Hydropower Development**

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## **ABSTRACT**

*The continuing and increased use of hydropower is a key part of the strategy to limit the extent of climate change. However, changes in climate may alter the availability of this natural resource, adversely affecting the financial viability of both existing and potential schemes. Previous work has developed a methodology for quantifying the potential impact of climate change on the financial performance of hydropower schemes. This paper presents an extension of the work through an examination of changes in risk resulting from changing climate. A case study provides an illustration of the process and the results further inform discussion of the implications for hydropower development.*

## **Introduction**

Several factors favour increased electricity generation from hydropower: rising demand for electricity, likely increases in fossil-fuel prices and the need for clean emission-free generation sources. Electricity production from hydroelectric installations, currently supplying just under one-fifth of global demand, is anticipated to triple by 2100 (Nakicenovic *et al.*, 1998). Unfortunately two drivers may prevent the realisation of this expectation. Firstly, the trend towards private capital in the industry implies that lower capital cost, rapid payback generation sources will be favoured and that higher rates of return will be expected. Secondly, greenhouse-gas induced climate changes will alter the timing and magnitude of river flows, leading to changes and perhaps reductions in hydropower production potential. Together, these issues have the potential to adversely affect the development of hydroelectricity worldwide.

## **A Risky Business?**

Studies have shown that river flows and hydropower production are sensitive to changes in precipitation and temperature (see Harrison & Whittington (2001) for a brief review). The authors extended the analysis to consider the impact of climate change on the financial performance of a proposed hydro scheme (Harrison & Whittington, in press). The scenarios of change were derived from the output of general circulation models (GCM) and resulted in significant changes in the economic viability of the scheme. In addition, a sensitivity study (Harrison & Whittington, submitted) was performed to provide information on the financial risk of changes in precipitation and temperature. Both studies found that the various scenarios of climate change resulted not only in changes in mean river flows and production, but also in alterations in their variance. These changes consequently led to changes in the variance of electricity sales income, which was identified as being a potential problem in cash flow terms.

Such changes in variance are a common result from studies investigating the effects of climate change on the hydrological regime. Arnell (1996) notes that the river basin tends to amplify changes in precipitation, resulting in larger changes in river flows. This effect can be attributed to the influence of the soil moisture levels in the river basin. Basin behaviour is non-linear and, as Figure 1 illustrates, a change in mean precipitation can result in river flows with both altered mean and altered variance. Given the changes in production and revenue variance, it was

considered prudent to examine, more closely, the effects of the river basin's non-linear response on variability, and in particular, its impact on the variability of the financial return, i.e., the project risk.

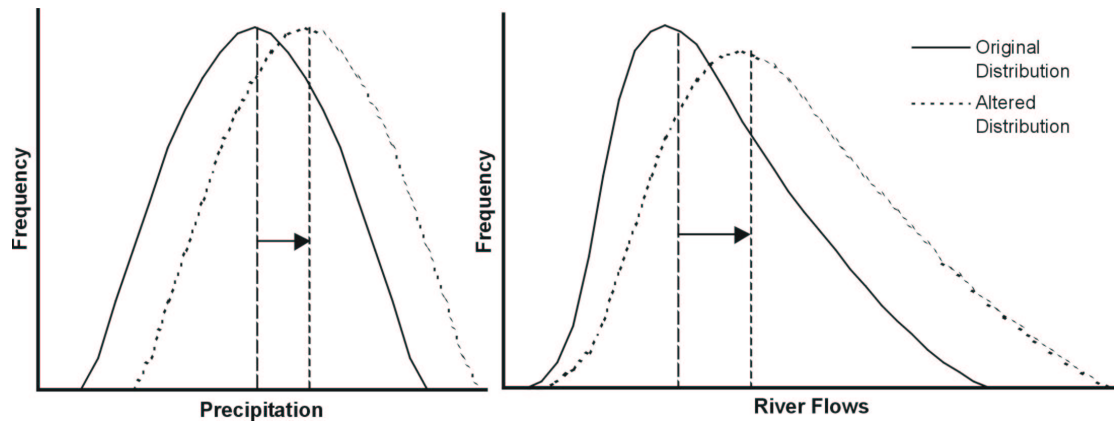


Figure 1: Alteration of river flow variance with changes in mean precipitation.

## Investment Risk

Sensitivity analysis provides an easily understood means of indicating project risk: the greater the sensitivity to a given variable the greater the risk (Arnold, 1998). However, the method gives no information on the probability of given outcomes, and further, that the changes are viewed in isolation where, in fact, the combined effects may be greater. Both sensitivity analysis and standard scenario analysis rely on the results from a single time series of river flows or, as in climate change studies, climate series. This is not prudent given that the timing of dry or wet periods consequently impact on production and economic projections, and may result in decisions that are based on overly optimistic or pessimistic values. Careful use of risk analysis techniques can remove some of these limitations.

Risk analysis techniques are well established in hydropower applications and are based on the use of synthetic river flow series. Statistically identical to the original series, the synthetic series provide alternative sequences of flows that may be used to examine the robustness of scheme operating procedures (Fiering, 1967) or the range of financial outcomes. Monte-Carlo simulations of project costs and benefits have also found use in hydropower applications (e.g., Gjermundsen & Jenssen, 2001). So far, risk techniques have found relatively little application in climate change studies, although a notable exception was the use of synthetic climate series by Mimikou and Baltas (1997) to assess the reliability of firm energy production from hydroelectric stations in central Greece. The authors' current contribution extends the scope of the analysis to focus on the impact on financial measures and the implications of changing risk on the preferences of investors.

Financial risk is generally an expression of the variance of the returns from a given investment. Where returns do not vary from the expected values (i.e. zero variance) the investment is regarded as risk free (e.g. Government Bonds). However, most other investments are not risk free and the rational investor would expect a higher rate of return (or risk premium) to compensate them for the risk. As such, the risk associated with a project, firm or market directly influences the choice of minimum acceptable rate of return used as the discount rate for net present value (NPV) assessments. This factor is of importance as the discount rate is critical in determining project profitability, the major factor in deciding between rival electricity sources.

Given this, there is potential for climate change to alter, further, the competitiveness of hydropower: analysis of this aspect is timely.

### Investment Risk Model

The investment risk model extends software already developed by the authors. The software possesses a series of components ranging from hydrological to financial models that allow predictions of river flows, energy production and financial performance based on scenarios of climate (Figure 2).

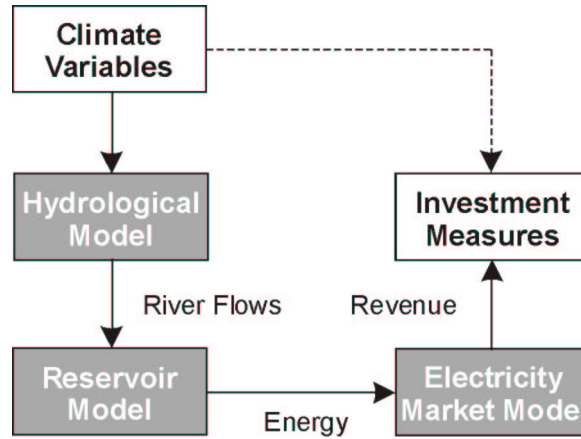


Figure 2: Schematic of appraisal software.

The software has been extended to allow it to perform Monte-Carlo simulations of scheme operation under different climate scenarios. It can generate and store a large number of synthetic series of both precipitation and temperature that can then be used to extract, automatically, the statistical properties of the resulting river flows, production and financial measures. Strictly speaking, the software, in its present form, cannot perform full Monte-Carlo simulations as only climate is varied. However, this allows the effects of climate change to be isolated.

The synthetic series are produced using a periodic Markov model that determines a given months precipitation, for example, from the previous months conditions, the statistical properties for that month and a random factor. The following equation details the periodic Markov model (Fiering, 1967):

$$c_{i,j} = \mu_j + \frac{\rho_j \sigma_j}{\sigma_{j-1}} (c_{i-1,j-1} - \mu_{j-1}) + t_i \sigma_j (1 - \rho_j^2)^{0.5}$$

Here  $c$  is the monthly climate variable to be predicted,  $\mu$  and  $\sigma$  are the monthly mean and standard deviation respectively,  $\rho$  is the correlation coefficient between consecutive months and  $t$  is a normal random number. The continuous and periodic indexes are  $i$  and  $j$  respectively.

### Example Risk Analysis

As with the authors' earlier work, the scheme chosen for the preliminary demonstration of this technique is the 1600 MW Batoka Gorge project, planned for the Zambezi River upstream of Lake Kariba (Figure 3). With only modest storage, the project is designed to operate as run-of-river to maximise system firm power delivery on a system level. Annual energy production is

expected to be approximately 9,100 GWh (BJVC, 1993). The software was found to provide a reasonably good simulation of the scheme.

The synthetic series were created by firstly analysing the relevant statistical properties of the historic precipitation and temperature record (as compiled by the Climatic Research Unit, UK) for the period covering 1961-1990. As a preliminary study, 250 pairs of 30 year long climate series were generated. The mean and standard deviations of precipitation and temperature, averaged over the whole set of artificial series, were found to match, closely, the properties of the historic data.

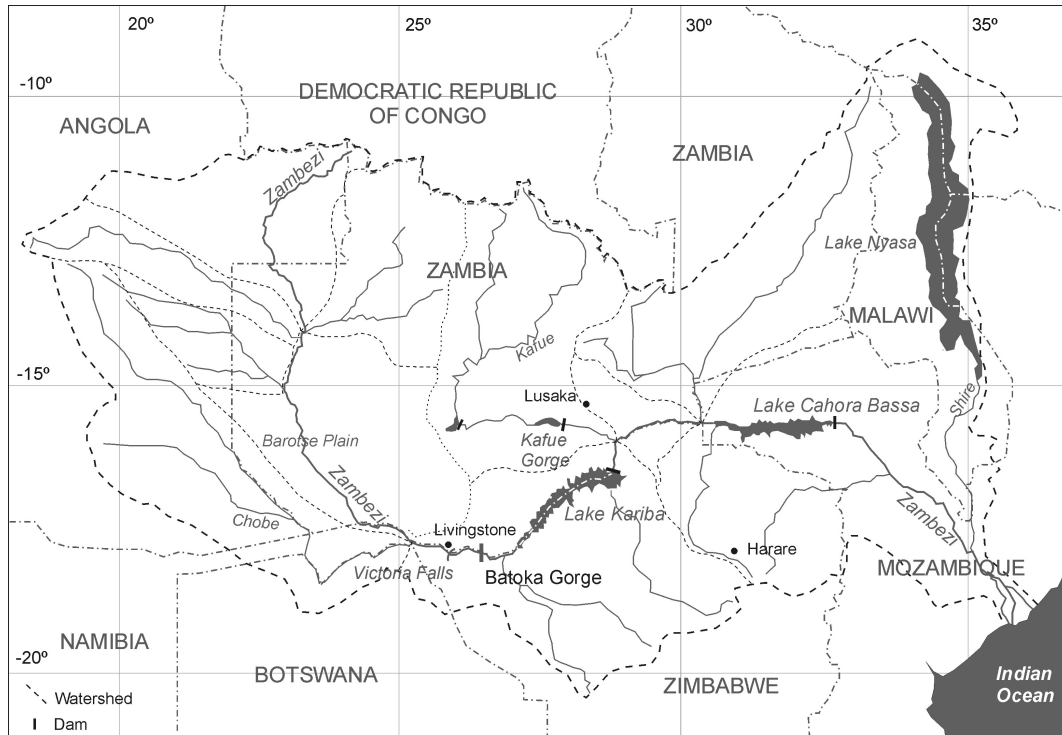


Figure 3: Zambezi River Basin.

### Application of Climate Change Scenarios

To illustrate the use of the software in conducting climate impact studies, three example climate change scenarios were considered. Scenario 1 comes from the results of the ECHAM4 general circulation model (GCM) developed by the German Climate Research Centre. The other 2 are from the HadCM2 GCM used by the Hadley Centre at the UK Meteorological Office. The difference between the Hadley scenarios is that Scenario 3 incorporates effects of atmospheric aerosols resulting in a slightly lower temperature rise. The scenarios represent conditions projected for the last quarter of this century and are given as changes in precipitation and temperature relative to the 1961 to 1990 mean conditions. The average annual changes are shown in Table 1.

A simulation was carried out for each of the 250 pairs of synthetic series under historic climate conditions and with each of the three climate change scenarios applied. The ultimate aim of the work was to examine how changes in climate may alter the variance of the scheme's financial returns, i.e. the financial risk. However, it is of interest to determine how the impact on other

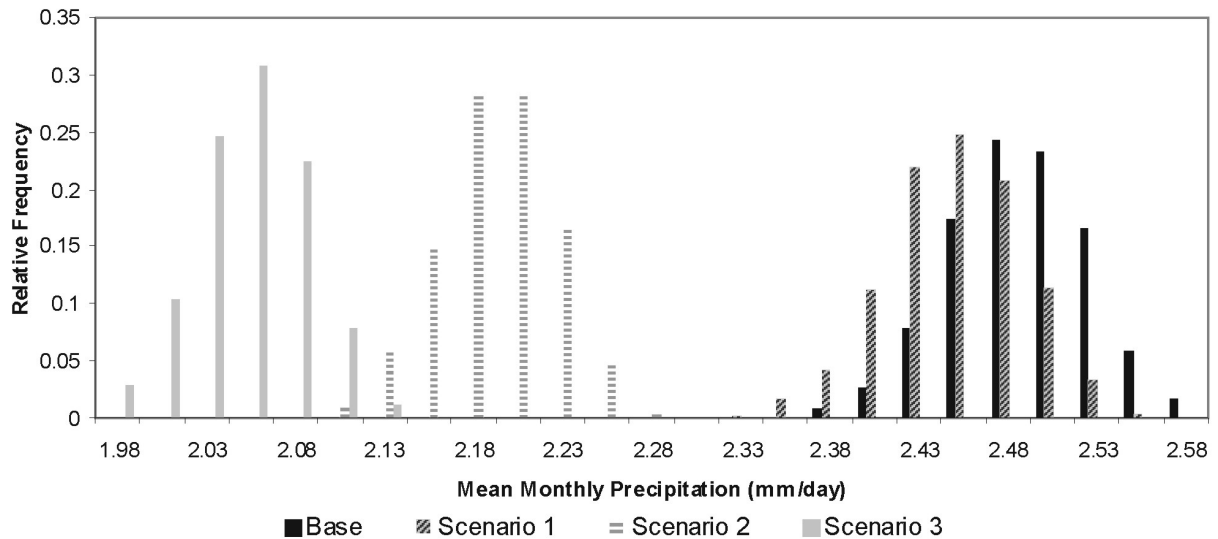
components of the climate-finance system (e.g. river flows) contribute to these changes. The following sections examine and compare the results from the climate simulations. To allow direct and meaningful comparison of variance between the scenarios where mean values are different, the indicator of interest is the normalised standard deviation or the coefficient of variation (CV), which is the ratio of the standard deviation and the mean expressed as a percentage. A summary of the mean values, nominal and normalised standard deviations are given in the 'Results Summary' section. The changes in variance can also be seen graphically in the histograms presented. Generally, flatter distributions indicate greater variance, but the intervals used mask the changes in some cases.

**Table 1: Change Scenarios Applied to Zambezi Basin**

Scenario	Change in climate variable	
	Precipitation	Temperature
Scenario 1	−1.6%	+5.0°C
Scenario 2	−12.5%	+5.3°C
Scenario 3	−17.6%	+4.4°C

## Climate Variables

The application of the GCM scenarios to the precipitation series alters the mean (as indicated in Table 1) and the variance. For both of the Hadley scenarios, the change in the standard deviation (Table 3) is larger than the mean change. Consequently, this lowers the CV by up to 4.5% (Table 4). However, with the mean increasing proportionately, albeit slightly, more than the standard deviation, Scenario 1 delivers a 1% increase in CV. The reduction in variance from the Hadley scenarios can be identified in Figure 4. Monthly temperature also experiences change: although there is virtually no change in the nominal standard deviation, the significant rises in mean temperature lowers CV by up to 20%.



*Figure 4: Histogram of mean monthly precipitation.*

## River Flows

Each of the scenarios results in significant decreases in river flow, with mean flows falling by 10 to 35% (Table 2). The amplification effect can be seen here as flows change by almost twice

that for precipitation. With even greater falls in their nominal standard deviation (11 to 45%), the CV is seen to decrease by less than 1% for Scenario 1, but by up to 15% for scenarios 2 and 3. This can be clearly seen in Figure 5.

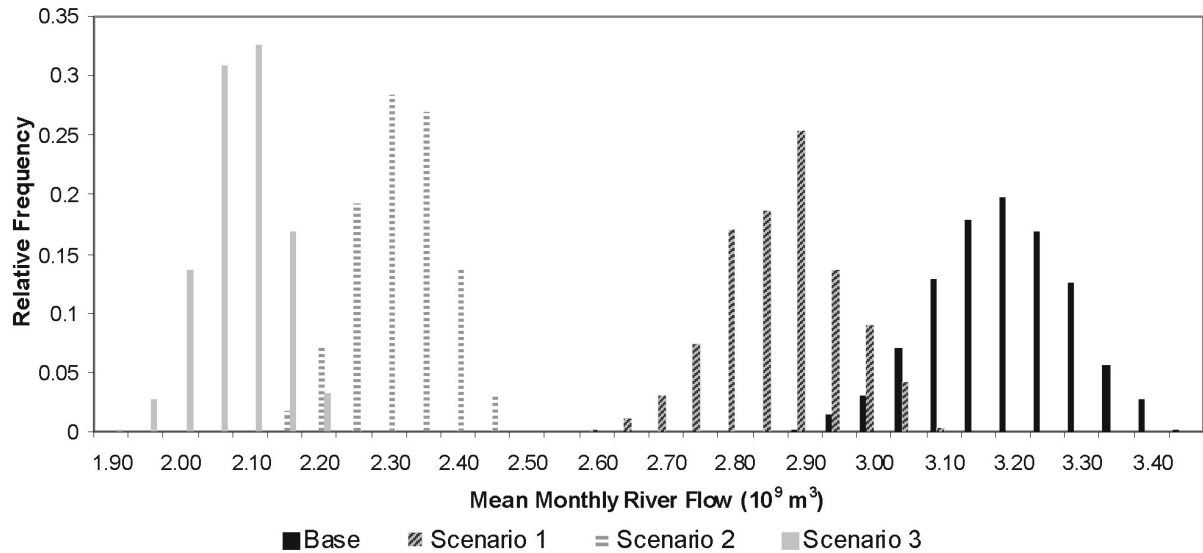


Figure 5: Histogram of mean monthly river flow.

## Production

Reservoir storage serves to limit the impact of changes in river flow on production, with greater storage tending to lower climate sensitivity. Although the reservoir is relatively small, the integrating effect restricts decreases in mean production to between 6 and 22%. The standard deviation only changes significantly for Scenario 3 (19%), but the CV rises under all GCM scenarios (between 5% for Scenario 1 and 52% for Scenario 3). The large change in CV under Scenario 3 can be seen in Figure 6.

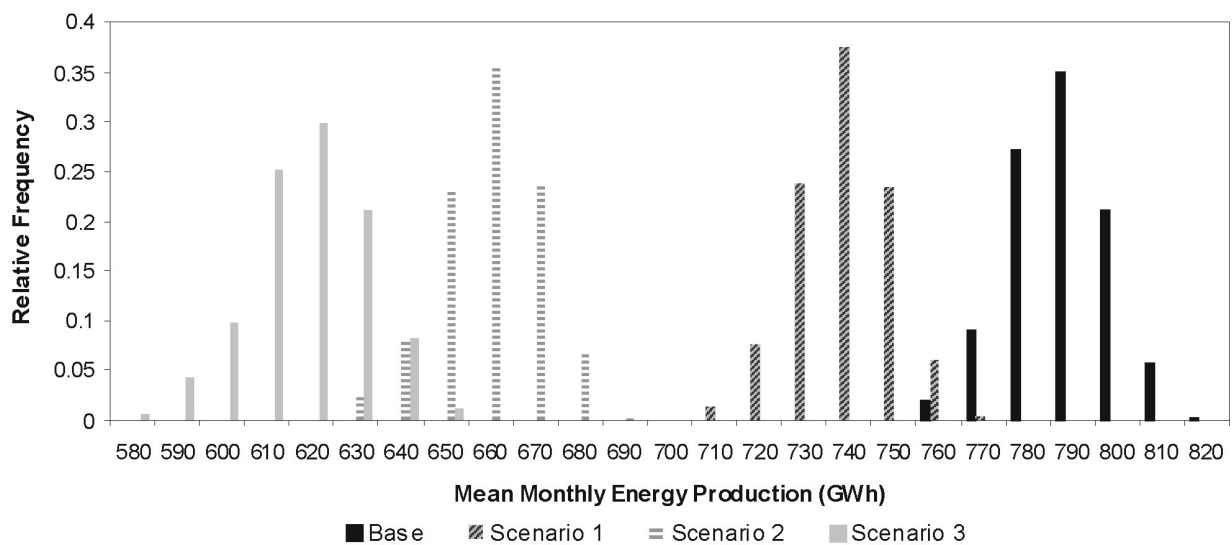


Figure 6: Histogram of mean monthly energy production.

## Financial Risk

Here, the financial performance of the scheme is primarily measured by the internal rate of return (IRR). An increased risk will manifest itself as an increase in the CV of the IRR. The use of a single price for energy sales means that sales income follows a similar pattern to production with the financial health of the installation adversely affected by all scenarios. The changes in climate reduce mean IRR by between 6% and 22%. For Scenarios 2 and 3 the mean IRR falls below the threshold for the project's economic viability (in this case a 10% discount rate), indicating that in these cases the project would not be viable. The nominal standard deviation of IRR reduces very slightly for Scenario 1 but increases by 6% and 27% for Scenarios 2 and 3, respectively. In consequence, the three scenarios result in an increased CV of between 6% and 64%. The changes can be seen in Figure 7 with the spread increasing with the severity of the change in climate.

Under the three scenarios presented here, the project would experience an increased climate-related risk of the magnitudes suggested by the changes in CV. An investor would expect an increased financial return from the scheme to compensate them for the increased risk, however, here only a lesser return is offered. Together, they appear to make hydropower a less attractive investment opportunity.

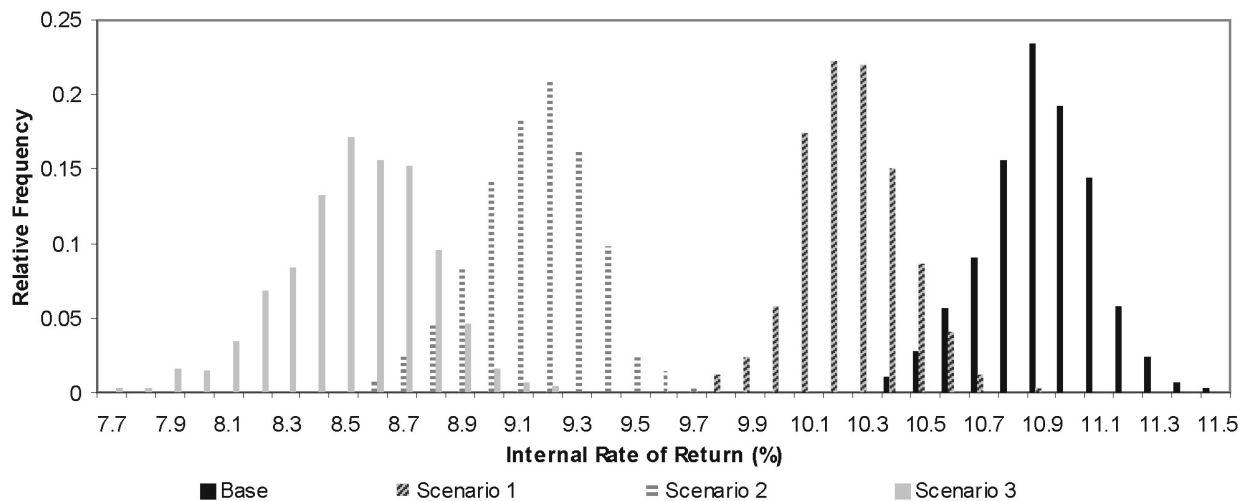


Figure 7: Histogram of IRR under climate scenarios.

## Results Summary

This section presents a summary of the statistical analysis of key indicators for each climate scenario: Table 2 shows the mean values across the synthetic series; Table 3 the standard deviation of the financial returns or the standard deviation of the means; and Table 4 the resulting coefficient of variation.



**Table 2: Results from Climate Change Scenarios (Mean)**

<i>Measure</i>	<i>Base</i>	<i>Scenario 1</i>	<i>Scenario 2</i>	<i>Scenario 3</i>
Precipitation (mm/month)	74.60	73.50	65.61	61.40
Temperature (°C)	21.94	26.96	27.27	26.33
River Flow (Mm <sup>3</sup> /month)	3.17	2.85	2.29	2.05
Production (GWh/month)	783.37	734.17	654.23	613.18
NPV (\$M)	88.98	23.92	-83.04	-136.20
IRR (%)	10.89	10.23	9.07	8.45

**Table 3: Results from Climate Change Scenarios (Standard Deviation)**

<i>Measure</i>	<i>Base</i>	<i>Scenario 1</i>	<i>Scenario 2</i>	<i>Scenario 3</i>
Precipitation (mm/month)	1.15	1.14	0.97	0.91
Temperature (°C)	0.03	0.03	0.03	0.03
River Flow (Mm <sup>3</sup> /month)	0.10	0.09	0.06	0.05
Production (GWh/month)	10.77	10.63	10.75	12.83
NPV (\$M)	18.25	17.58	17.94	20.74
IRR (%)	0.19	0.19	0.20	0.24

**Table 4: Results from Climate Change Scenarios (Coefficient of Variation)**

<i>Measure (%)</i>	<i>Base</i>	<i>Scenario 1</i>	<i>Scenario 2</i>	<i>Scenario 3</i>
Precipitation	1.54	1.56	1.47	1.48
Temperature	0.16	0.13	0.13	0.14
River Flow	3.07	3.05	2.73	2.63
Production	1.38	1.45	1.64	2.09
NPV	20.51	73.49		
IRR	1.71	1.82	2.18	2.80

## Discussion

The scenarios presented here represent only a sample of the many climate change scenarios that may eventually occur, which include many that suggest increased precipitation. It is difficult to determine, objectively, the most likely scenario of change, given that there is major uncertainty attached to the probability of the climate change scenario. Investment decision-making will continue to rely on subjective estimates, and although the techniques used here add a further degree of uncertainty and complexity, with refinement they could be used as an effective tool. Additionally, the scenarios used here should be regarded as worst case: they compare the effects of climate change in isolation and assume a step change in climate and non-evolving operational practice. A more realistic approach would be to assume evolving climate and evolving programme of operational practice.

Despite the limitations of the analysis, the results suggest that changes in climate result in a change in the financial risk faced by this station and that the risk appears to increase as the level of precipitation decreases. However, to confirm this trend, further study will be necessary. Without knowledge of the overall risk profile for the project, it is not possible to say whether the increased climatological risk will be sufficient to influence the investor's choice of discount rate or the eventual decision about whether or not to proceed with the project. Development of a Monte-Carlo simulation that includes other project variables could go some way to answering this question.

## **Conclusions**

The threat of climate change necessitates the continuing and increased use of renewable sources including hydropower. However, deregulation increases private investment in the ESI and may create difficulties for hydro. This may be exacerbated by the impact of climate change on the resource. Previous studies by the authors indicated that hydropower economics showed significant sensitivity to changes in precipitation and temperature. The studies also found that, in addition to mean changes, there were changes in the variance of production and sales revenue. This paper set out to provide a preliminary analysis of whether such changes would lead to changes in the financial risk faced by the project, given that perceptions of risk play a major part in project appraisal. Using a case study, a Monte-Carlo analysis was carried out using synthetic precipitation and temperature time series that were generated from the historic climate record. The application of several climate change scenarios to the synthetic series allowed an examination of the influence of climate on the magnitude and variance of financial returns. The simulations found that for the climate change scenarios used, there was an increase in the variance of the financial returns and therefore an increased risk, with a greater increase in risk resulting from greater decreases in precipitation. However, without knowledge of the overall risk profile of the study scheme it was not possible to say whether the changes in climatological risk would alter the investment decision. What is apparent is that climate change may well be a double-edged sword for hydropower: the changes in climate will affect not only the expected return from hydroelectric installations but also the financial risk that they face.

## **Dedication**

On the 11th of March 2002 and shortly before this work was revised, Professor Bert Whittington was tragically killed in a road accident in Edinburgh. He was aged fifty-six and leaves his wife Helen and two sons, Barry and Alan. Bert became Professor of Electrical Power Engineering at the University of Edinburgh in 1994 and, more recently, acted as consultant to the Scottish Executive and Special Advisor to the UK Parliamentary Select Committee on Energy Policy. He held fellowships with the Institution of Electrical Engineers, the Royal Society of Arts and the Royal Society of Edinburgh. A tremendous loss to his family, friends and colleagues, Bert Whittington will be remembered as the highly intelligent, witty and talented man that he was and for the inspiration and good humour that he gave to others.

## **Acknowledgements**

The authors wish to thank the Zambezi River Authority for their permission to use and publish data relating to the Batoka Gorge scheme, and Knight Piésold Ltd for supplying the relevant data. The monthly climate time-series data was supplied by the Climate Impacts LINK Project (UK Department of the Environment Contract EPG 1/1/16) on behalf of the Climatic Research Unit, University of East Anglia.

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*The late Bert Whittington, PhD, CEng, was Professor of Electrical Power Engineering at the University of Edinburgh. He was also a Consultant to the Scottish Executive and Special Advisor to the UK Parliamentary Select Committee on Energy Policy. He was a Fellow of the Institution of Electrical Engineers, and a Fellow of both the Royal Society of Arts and the Royal Society of Edinburgh.*